Lecture 5
Image Characterization

ch. 4 of *Machine Vision* by Wesley E. Snyder & Hairong Qi

Spring 2024

16-725 (CMU RI) : BioE 2630 (Pitt)

Dr. John Galeotti

Digital Images

- How are they formed?
- How can they be represented?

Image Representation

- Hardware
  - Storage
  - Manipulation
- Human
  - Conceptual
  - Mathematical

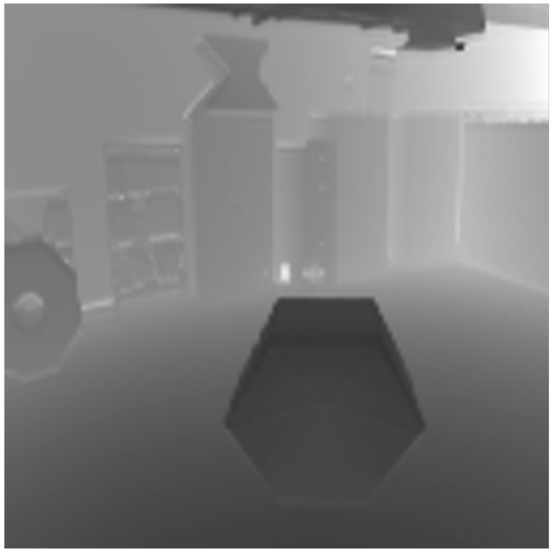
Iconic Representation

- What you think of as an image, …
  - Camera
  - X-Ray
  - CT
  - MRI
  - Ultrasound
  - 2D, 3D, …
  - etc

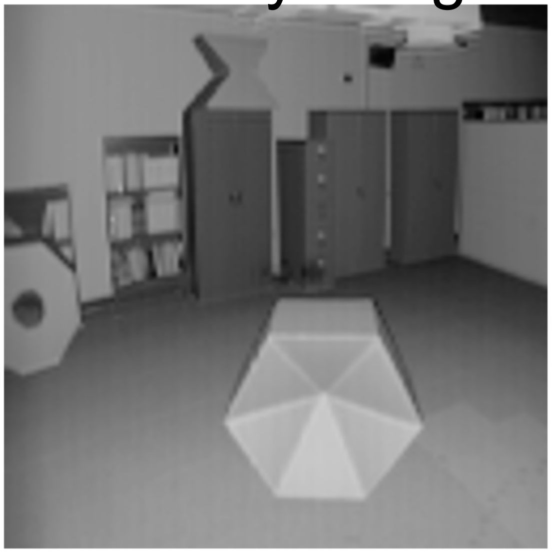
Iconic Representation

- And what you might not

Range Image



Corresponding Intensity Image



Images from CESAR lab at Oak Ridge National Laboratory,
Sourced from the USF Range Image Database:
http://marathon.csee.usf.edu/range/DataBase.html
Acknowledgement thereof requested with redistribution.

Functional Representation

- An Equation
  - Typically continuous
- Fit to the image data
  - Sometimes the entire image
  - Usually just a small piece of it
- Examples (Quadratic Surfaces):
  - Explicit: $z = ax^2 + by^2 + cxy + dx + ey + f$
  - Implicit: $0 = ax^2 + by^2 + cz^2 + dxy + exz + fyz + gx + hy + iz + j$

Linear Representation

- Unwind the image
  - "Raster-scan" it
- Entire image is now a vector
  - Now we can do matrix operations on it!
  - Often used in research papers

Probabilistic & Relational Representations

- Probability & Graphs
- Discussed later (if at all)

Spatial Frequency Representation

- Think “Fourier Transform”
- Multiple Dimensions!
- Varies greatly across different image regions
- High Freq. = Sharpness

- Steven Lehar’s details: http://sharp.bu.edu/~slehar/fourier/fourier.html

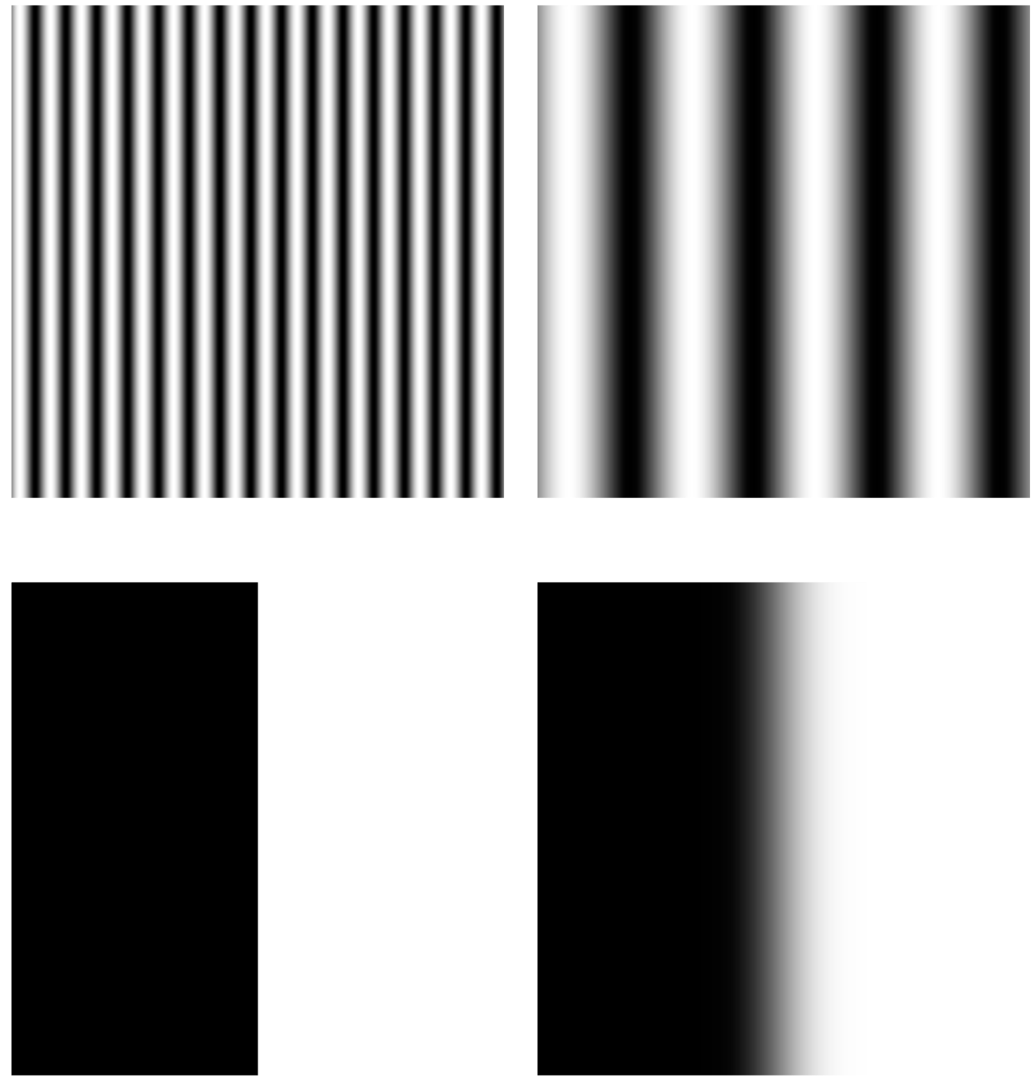
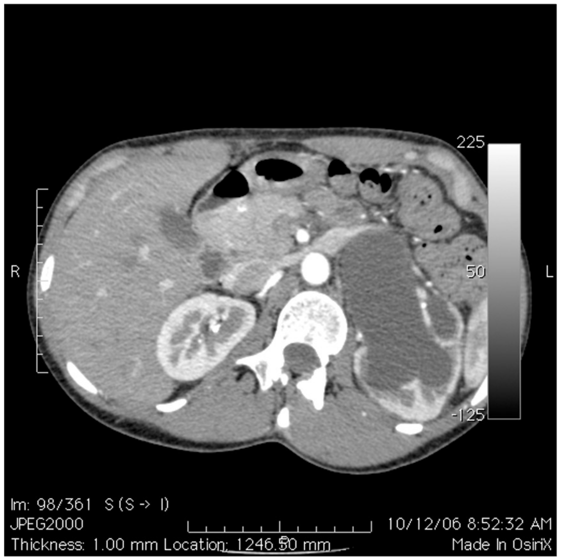


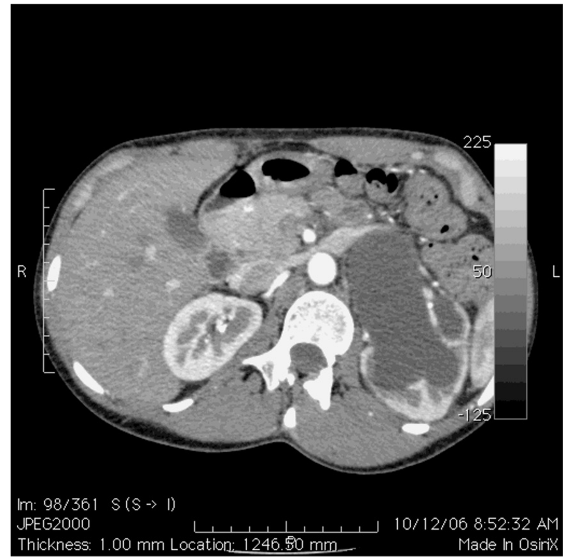
Image Formation

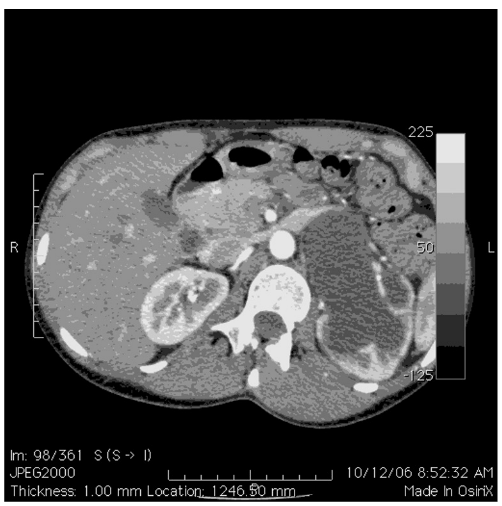
- Sampling an analog signal
- Resolution
  - # Samples per dimension, OR
  - Smallest clearly discernable physical object
- Dynamic Range
  - # bits / pixel (quantization accuracy), OR
  - Range of measurable intensities
    - Physical meaning of min & max pixel values
    - light, density, etc.

Dynamic Range Example

(A slice from a Renal Angio CT: 8 bits, 4 bits, 3 bits, 2 bits)







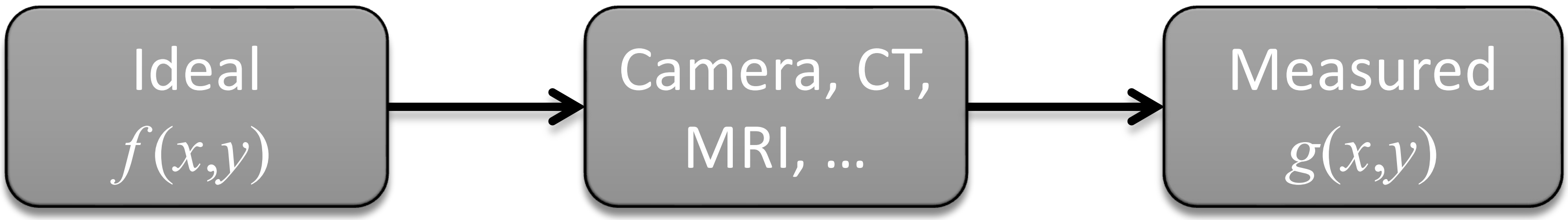
An Aside: The Correspondence Problem

- My Definition:
  - Given two different images of the same (or similar) objects,

    for any point in one image

    determine the exact corresponding point in the other image
- Similar (identical?) to registration
- Quite possibly, it is THE problem in computer vision

Image Formation: Corruption



- There is an ideal image
  - It is what we are physically measuring
- No measuring device is perfect
  - Measuring introduces noise
  - $g(x,y) = \mathrm{D}(\ f(x,y)\ )$, where D is the distortion function
- Often, noise is additive and independent of the ideal image

Image Formation: Corruption

- Noise is usually not the only distortion
- If the other distortions are:
  - linear &
  - space-invariant

  then they can *always* be represented with the convolution integral!
- Total corruption:

$$g(x,y) = \iint_{-\infty\ldots\infty} f(\alpha,\beta)\,h(x-\alpha, y-\beta)\,d\alpha\,d\beta + n(x,y)$$

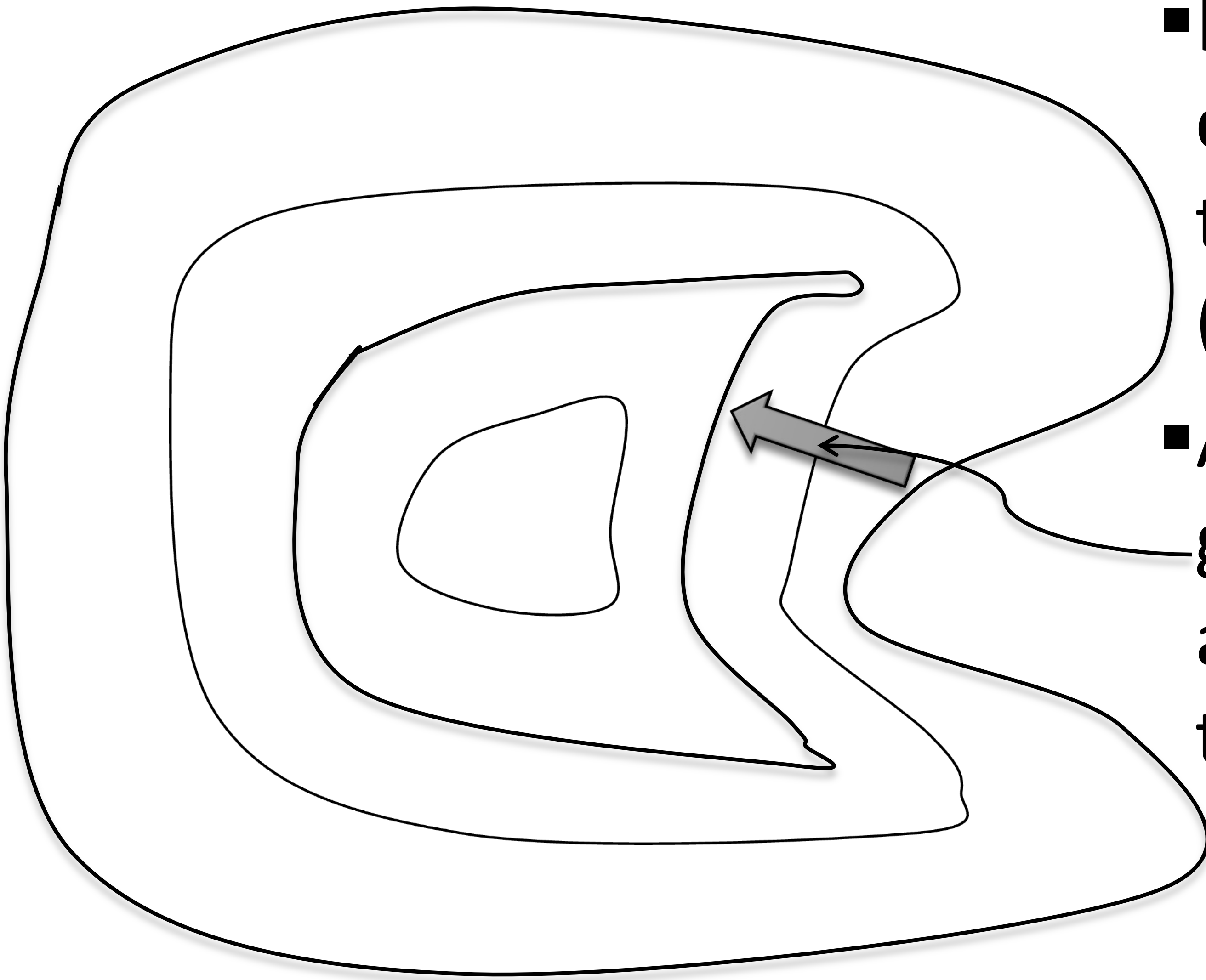
The image as a surface

- Intensity $\rightarrow$ height
  - In 2D case, but concepts extend to ND
- $z = f(x, y)$
- Describes a <u>surface</u> in space
  - Because only one z value for each x, y pair
  - Assume surface is continuous (interpolate pixels)

Isophote

- "Uniform brightness"
- $C = f(x, y)$
- A <u>curve</u> (2D) or surface (3D) in space
- Always perpendicular to image gradient
  - Why?

Isophotes & Gradient



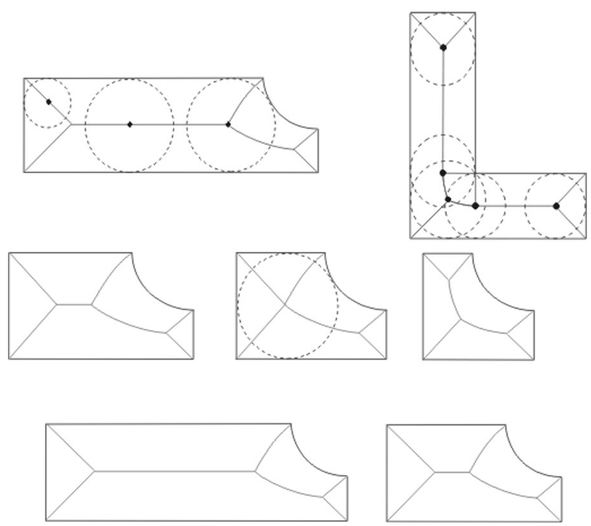
- Isophotes are like contour lines on a topography (elevation) map.
- At any point, the gradient is always at a right angle to the isophote!

Ridges

- One definition:
  - Local maxima of the rate of change of gradient direction
  - Sound confusing?
  - Just think of ridge lines along a mountain
  - If you need it, look it up
    - Snyder references Maintz

Medial Axis

- Skeletal representation
- Defined for binary images
  - This includes segmented images!
- "Ridges in scale-space"
  - Details have to wait (ch. 9)



http://sog1.me.qub.ac.uk/Research/medial/medial.php

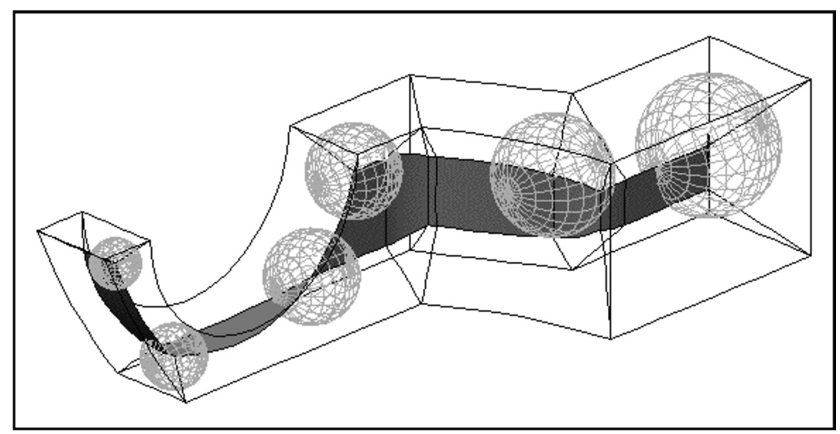
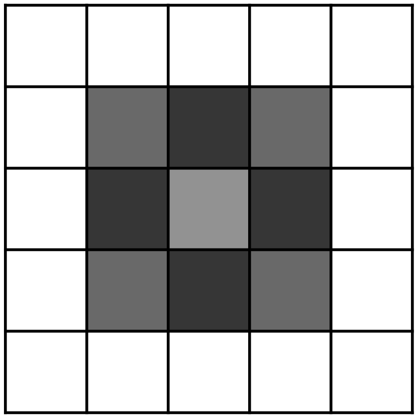


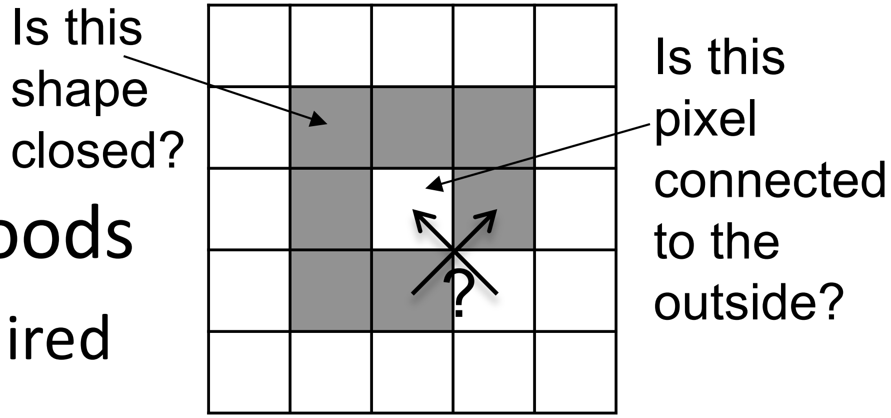
Image courtesy of TranscenData Europe
http://www.fegs.co.uk/motech.html

Neighborhoods

- Terminology
  - 4-connected vs. 8-connected
  - Side/Face-connected vs. vertex-connected
  - Maximally-connected vs. minimally-connected (ND)



- Connectivity paradox
  - Due to discretization
- Can define other neighborhoods
  - Adjacency not necessarily required



Curvature

- Compute curvature at every point in a (range) image
  - (Or on a segmented 3D surface)
- Based on differential geometry
- Formulas are in your book
- 2 scalar measures of curvature that are invariant to viewpoint, derived from the 2 principal curvatures, (K_1, K_2):
  - Mean curvature (arithmetic mean)
  - Gauss curvature (product)
    - =0 if either K_1=0 or K_2=0